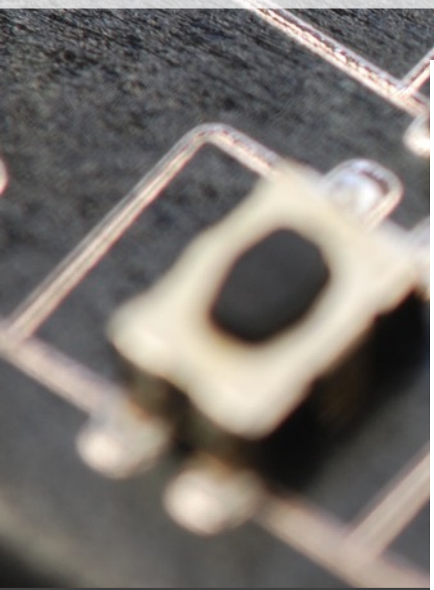
Neotech AMT

Advanced Manufacturing Technologies for 3D Printed Electronics



Scalable 3D Printed Electronics – "Fully Additive" To High Volume Manufacture

Dr. Martin Hedges – Managing Director

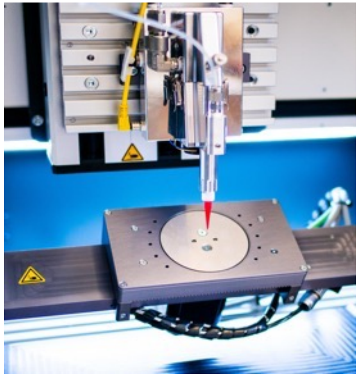
10.06.2022

Agenda

1. Company Overview
2. Designing a 3D Printed Electronics Process
3. Application Examples
4. Beyond Simple Circuits
5. 3D Print Systems

Introduction

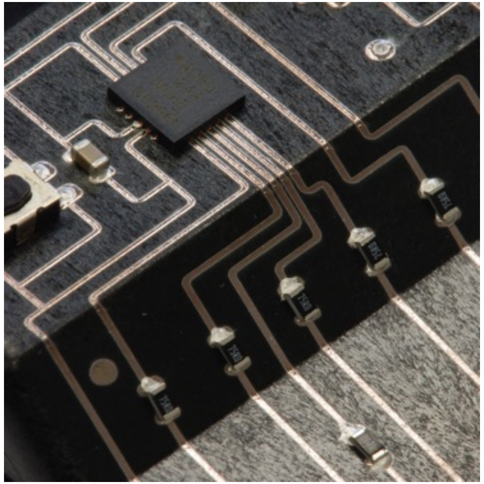
- Neotech AMT GmbH, Nuremberg, Germany
- Specialist machine tools for 3D Printed Electronics
- Pioneering 3D PE development since 2009
- First 3D capable system installed in 2010
- First mass-production capable system, 45X, built in 2012
- Active in a wide variety of industries



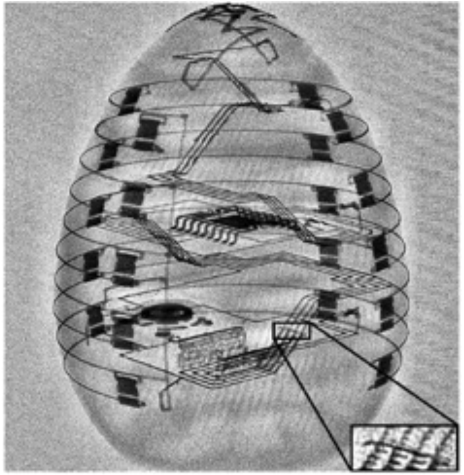
What is 3D Printed Electronics?

3D PE is the addition of printed electronics functionality, sometimes in combination with classical SMDs onto and/or into structural components to create mechatronic systems

Printed Electronics on a 3D Substrate



Printed Electronics in a 3D Substrate



Benefits of 3D Printed Electronics

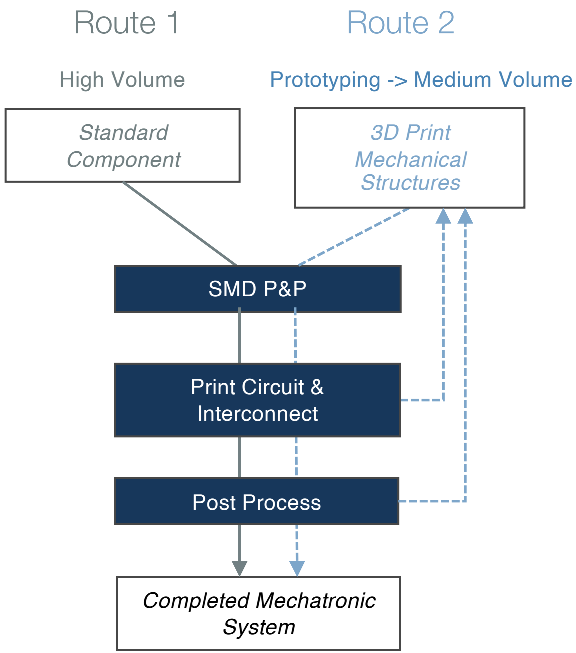
Design Flexibility	Economics	Environmental
Integrated Products	Reduced Part Count	Reduced Materials Mix
Flexibility of Shape	Shorter Process Chains	Simplified Recycling
Minaturisation	Reduced Materials Use	Reduced Material Quantity
New Functionality	Increased Reliability	Reduced Parts Tourism

3D PE Process Chains

Two basic process chains exist for 3D Printed Electronics:

Route 1: Print on 3D Substrates. Electonics are intergrated onto the surface of a standard components (mouldings, composites etc.)

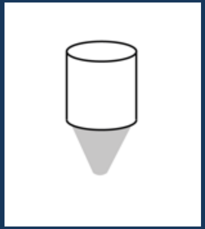
Route 2: “Fully Additive Manufacture” – classical structural AM (via FFF, SLA, IJ…) is combined with 3D PE processes



2. 3D PE Processes, Systems & Strategies

Machine Tools for 3D PE

3D PE machine tools containing a variety of print, pre- and post-processing tools with integrated software:

Print Platforms	Print/Functionalising Tools	Pre/Post-Processing
		
Freeform 3D – 5 axis motion (CNC)	Piezo/Valve Jetting	Plasma Cleaning
+ CAD/CAM Software	Aerosol Based	Sintering (Light/Laser)
	Ink Jetting (Single & Multi-Nozzle)	UV Curing
	Dispensing	Adaptive Tool Path Vision System
	Structural Build (FFF, Dispensing, Jetting)	Laser Ablation
	SMD Pick & Place	CNC Machining

Print Technologies for 3D Electronics

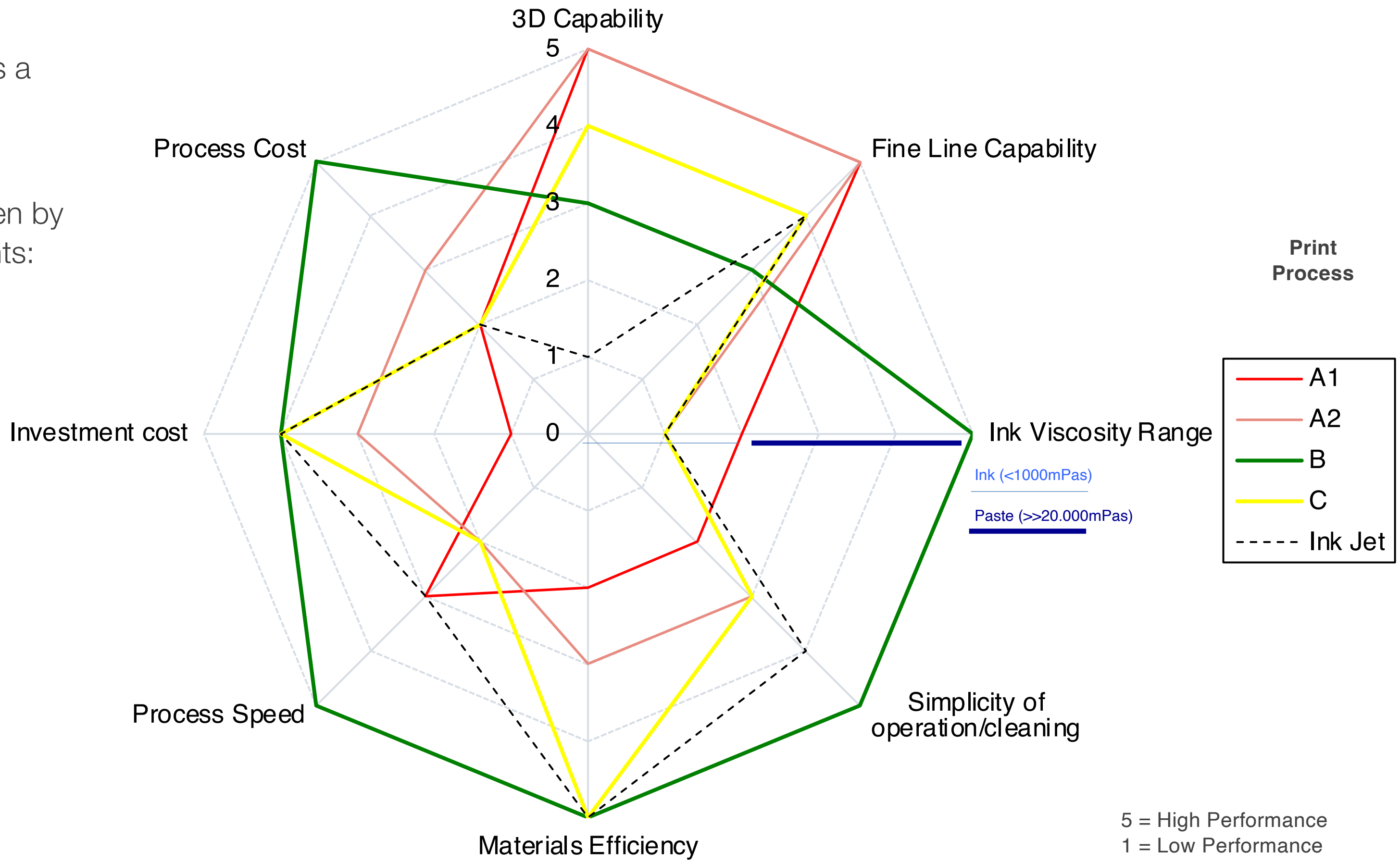
Method	Piezo/Valve Jet	Aerosol Based Jetting	Multi Nozzle Ink Jet	3D Dispensing	Print + Laser Ablation	Pneumatic Spray	US Spray
Standoff Distance	1-5mm	1-10mm	<1mm	1x Nozzle ID	N/A	>5mm	>5mm
Viscosity Range	50-200.000mPas	1-20mPas	to 20mPas	to 1.000.000 mPas	N/A	600-150.000mPas	ca. max. 50mPas
Particulate Size	Nano Scale-Micron (max. ca. D90=6um with 50um nozzle)	Nano Scale	Nano Scale	Nano Scale-Micron Max. size depends on nozzle diameter	Nanopartices & Micron scale	Nano Scale	Nano Scale
Printed Line Width	300-1000µm	20-250µm	50-1000um	50um-1000um	10um	Area	Area
Typical Thickness	>20µm	0,5-10µm	0,5-10µm	2-10+um	2-10+um	<10um	<5um
Typical Process Speed	15-100mm/s	1-10mm/s	5-50mm/s	10-20mm/s	1000-4000+mm/s	to ca. 300mm/s	to ca. 100mm/s

Note: exact capabilties depend strongly on factors such as materials deposited, substrate surface conditon and 3D geometry

Print Head Selection

Each print process has a unique combination of characteristics.

Process selection driven by application requirements:



5 = High Performance
1 = Low Performance

Complex Functionality for 3D Printed Electronics

3D PE can add circuits and other simple functionality such as sensors, antenna, heaters.

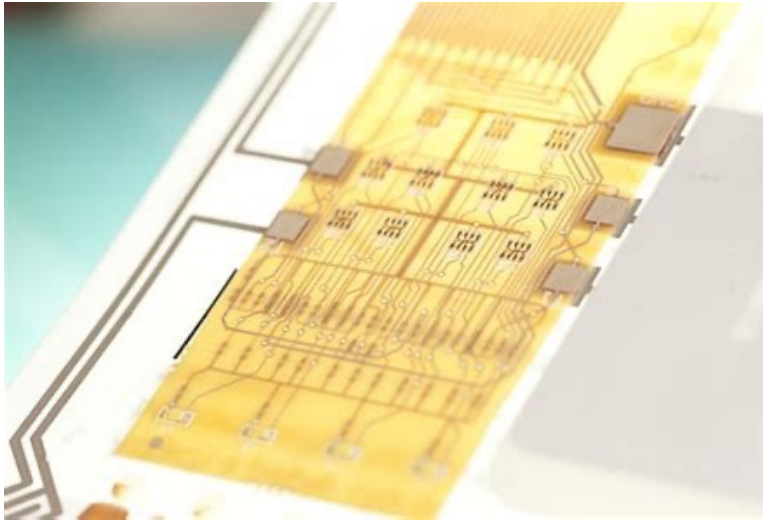
What about more complex devices?

On-going developments in 2D Printed Electronics for complex printed devices:

Passive Devices: Resistors, capacitors, inductors, transformers, diodes

Active Devices: transistors & transistor based circuits

Why not in 3D PE?



https://www.techdesignforums.com/blog/2014/04/04/printed-electronics-demonstrator/

Printed Interconnection of SMDs

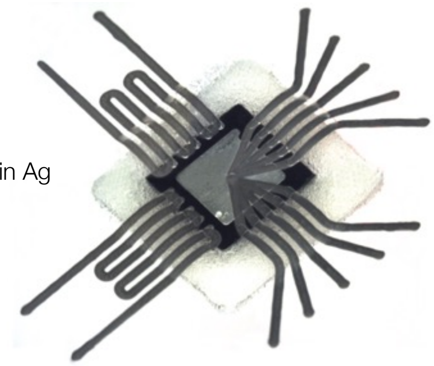
Benefits

- Low temperature route, no soldering
- Simplified material mix, simplified re-cycling
- Simplified processing
- Robust package, especially when embedded
- Can exhibit low signal loss in high frequency applications >50GHz (compared to wire bonding)

QFN (Quad Flat No-lead)
Microcontroller

Embedded in PC Substrate

Interconnect/Circuit 200µm in Ag



Neotech AMT GmbH

3. Markets & Applications

Market Opportunity

3D Printed Electronics is a very transferable technology resulting in a large range of potential applications.

Wide and expanding range of multi-bn Euro Markets:

Electronic manufacturing services, € 46bn in 2019 [5]

Mobile Phones [6]	Automotive Electronics[7]	LED Lighting [8]	Power/Industrial Electronics [9]	Medical Devices [10]
US$ 400bn in 2020	US$ 217bn in 2019	US$ 145bn in 2026	US$ 51bn in 2023	US$ 6bn in 2021

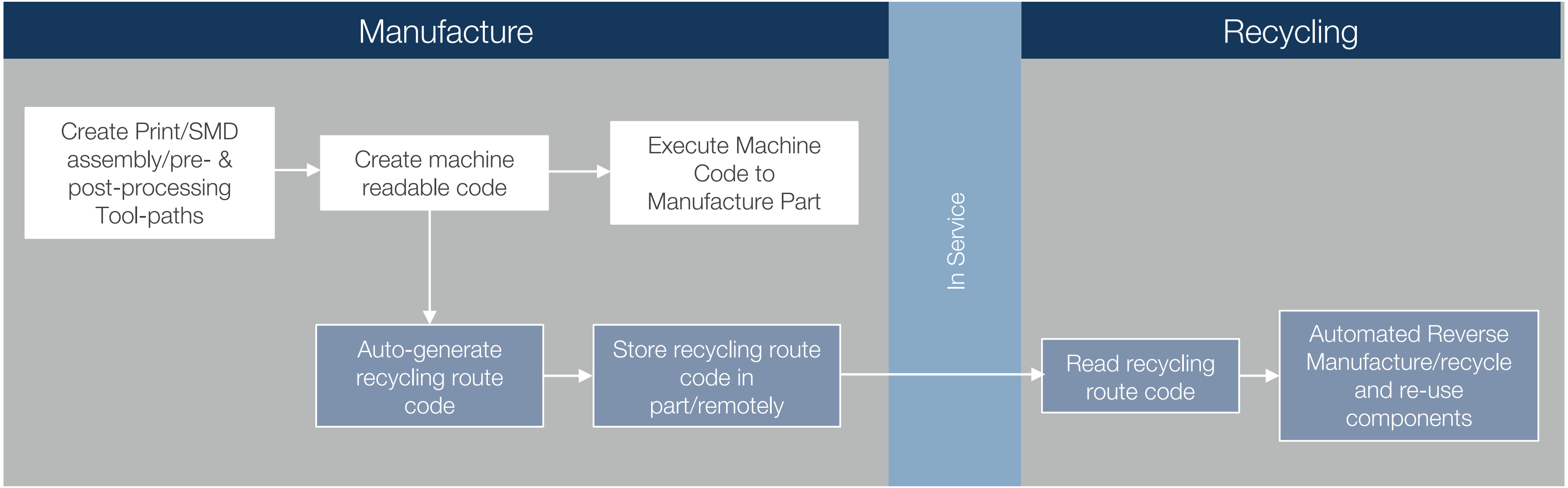
IoT > US$ 300bn in 2020 [4]

Plus: Aerospace, White Goods...

Enabling More Sustainble Electronics

AM of Electronics is CAD Driven

Potenital to automate re-use and recycling



Case Study - Reusable “Lumnaire”

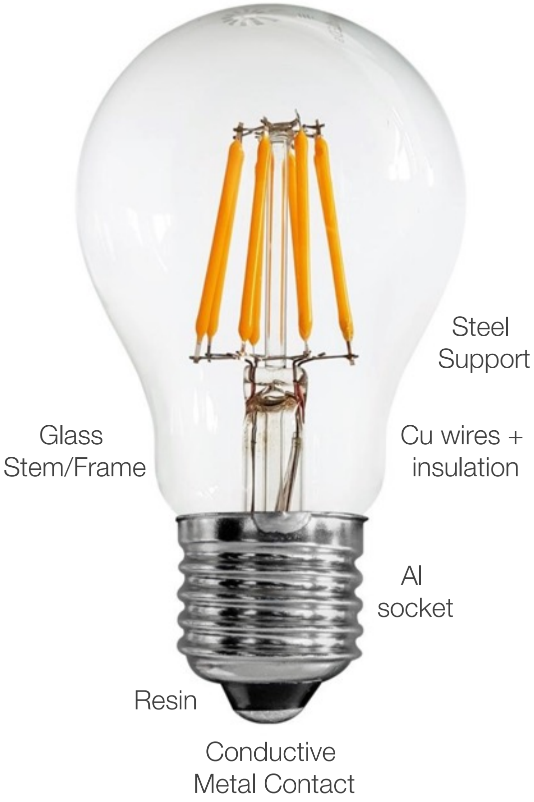
Next few years, billions of LED products are going to reach the end of their useful life

Complex mix of materials make up and LED lightbulb:
1. Structural - Min. 10 materials plus
2. PCB (multiple resins, glass fibre, Cu, Ni, solder) plus
3. Electronic Components and (Controller, Resistors, Capacitors, LEDs)

Over 95% of an LED bulb is recyclable but via lengthy multi step processes:
LED bulbs crushed and separated (Ferrous & Non-Ferrous Metals and Glass)
Energy intensive remelted for re-use

E-Waste components PCB, LED strip have many more mixed materials that cannot be reused.

No direct reuse of any SMD components



First Prototype/Proof of Concept

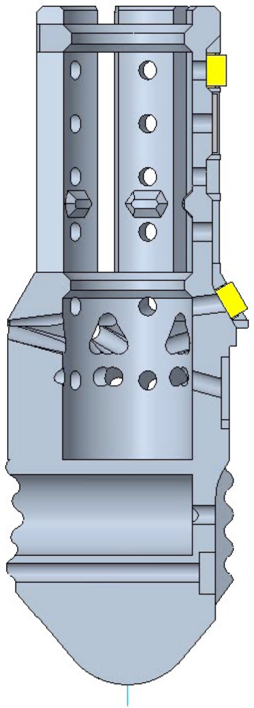
Simplified Materials Mix:
1x mechanical body material (FFF printed PC)
1x circuit material (Ag/resin paste <0.2g)
Plus SMDs

Full traceability of all components & materials

Refurbishable + reusable.

Easily Recyclable – Automated with low energy intensity.

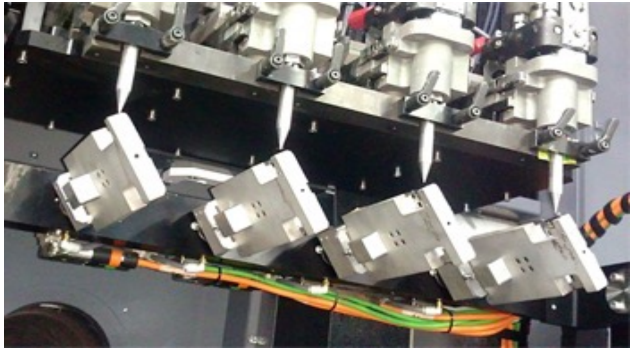
<u>To Do</u>
Optimise circuit & SMD mix
Print LED lenses/encapsualisation
Glass Cover/Bulb
Moulded body of reduced mass.
Test & optimise refurbishment process methodology



MID Application Examples

Mobile Communications - Antenna

1. Printing Ag inks for antenna and circuits on moulded resins: PC/ABS, PA
2. RF Performance: matches industry standard, can show cost reduction (design dependent)
3. Adoption slowed by phone design changes: metal frame, 5G at chip level…
4. Potential in next generation phones (3D shaped glass)



Multi-station Printing.
Courtesy: LITE-ON Mobile Mechanical SBG

Demonstration Antenna
Courtesy: LITE-ON Mobile Mechanical SBG

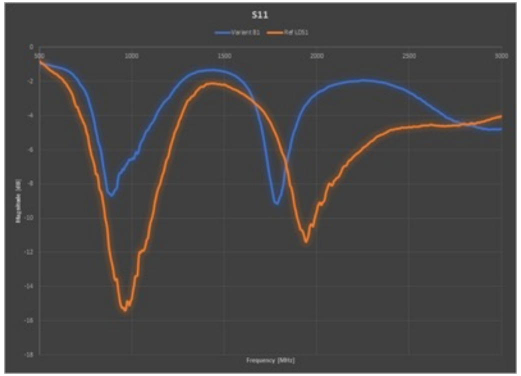
Antenna - Cost Reduction - Print and Laser Trim

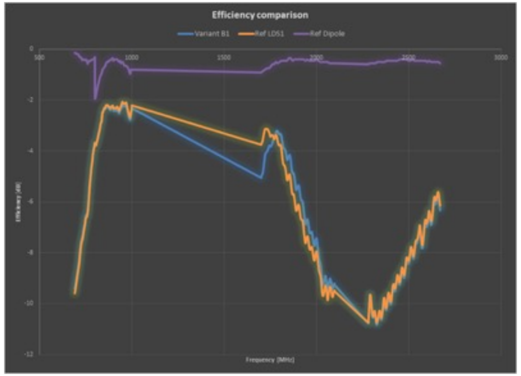
Particle free Ag printed on PC

“Coarse” printing to reduce cycle time - Laser trimmed at over 1m/s

Good frequency matching at main frequencies (900mHz and 1.8GHz)

Efficiency matches production standard (LDS route)





Antenna for IoT Device

Project by Sentium/Murata/University Erlangen Nuremberg - FAPS Institute

Combination of 3D PE with a multi-stack LPWAN IoT device to complete the mechatronic system.

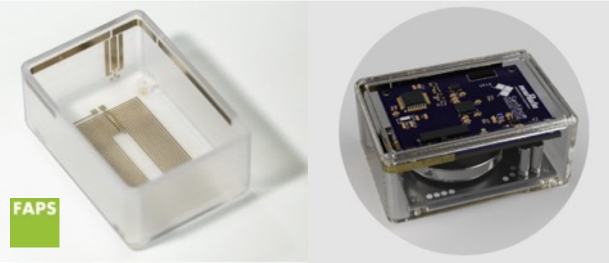
Two Antenna printed on PC housing for the IoT Device:

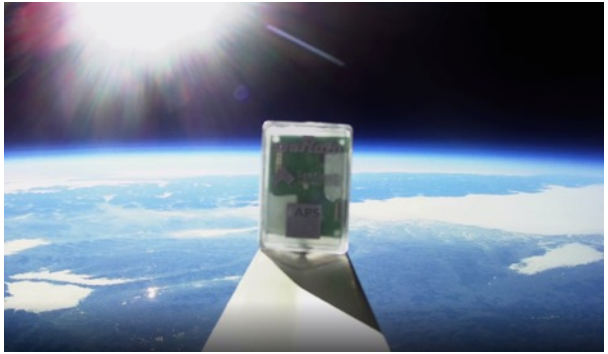
- Base Antenna is NFC for writing and reading data to and from the device motherboard.

- Wall Antennas are combined LoRa (Long Range Wide Area Network) and NB-IoT (Narrowband Internet of Things) antennas for communicating with gateways.

IoT device was sent into the stratosphere with a helium balloon.

The sensor covered a distance of nearly 200 km and reached an altitude of over 40,000 meters with sensor data as well as the position of the device could be monitored during the mission.





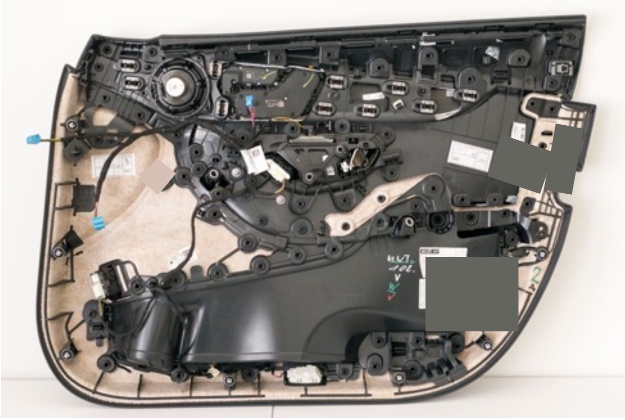
Automotive Trends Provide Opportunity for 3DPE

Key Trends[1] in Automotive :

1. Electric vehicles. Petrol/diesel fuelled vehicles phased out world wide through the 2030s. Opportunities from electrification and weight reduction requirements.

2. Increased levels of autonomy. ‘Advanced Driver Assistance Systems (ADAS)’ becoming the norm. Opportunities for sensor, heaters and antenna.

3. Differentiation shifts from powertrain to interior/cockpit. Marketing battleground. Opportunity for additional functionality on conformal surfaces in the cockpit while facilitating more efficient manufacturing.



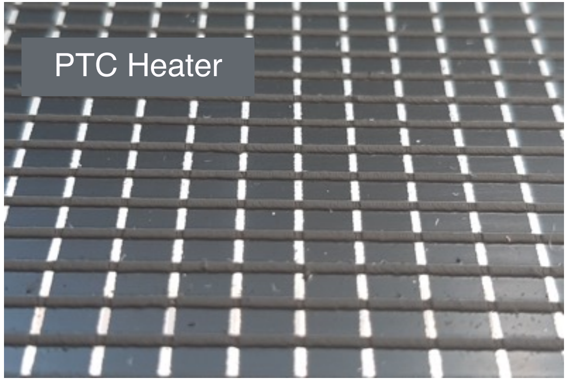
Door Panel Interior

[1] Shift to electric vehicles to drive printed electronics automotive market to $12.7 bn by 2031

[1] https://www.idtechex.com/en/research-report/printed-and-flexible-electronics-for-automotive-applications-2021-2031-technologies-and-markets/806

Automotive Applications in Development

Functionality	Current Development
Heater Patterns	Lidar/Radar
	Rear Windscreen
	Steering Wheel, Cabin Interior (PTC)
Lighting	Cabin Interior (LEDs) with touch sensor control
	Optical Waveguides
Sensing	Touch Sensor
	Temperature Sensor
	Pressure Sensor

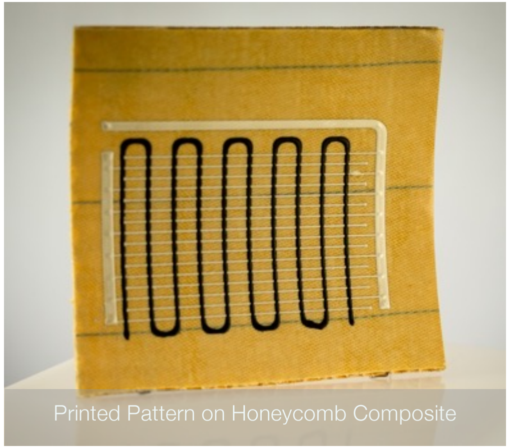


Commercial Aerospace

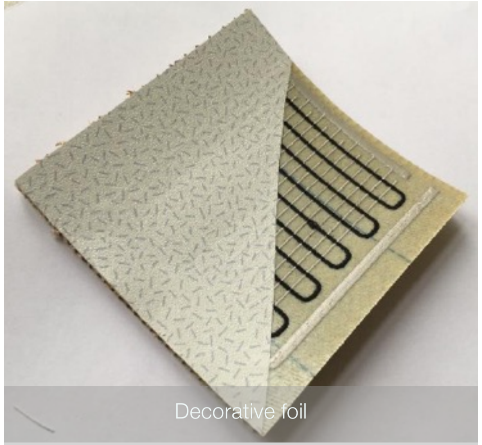
Cabin Interior - Ag circuit with PTC resistive heater: light weight, safe & integrated into cabin side wall

Additional applications include sensor structures, antenna, lighting

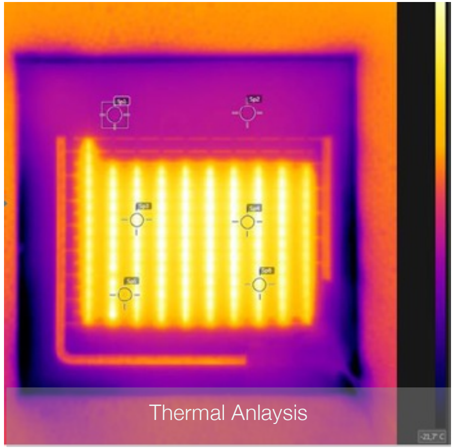
Long lead time to move to production – slow/complex adoption of new technology



Printed Pattern on Honeycomb Composite



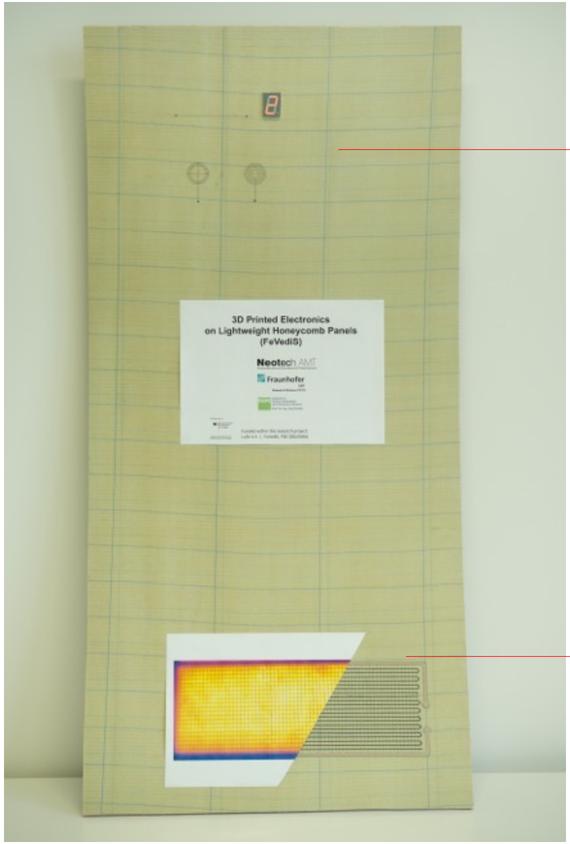
Decorative foil

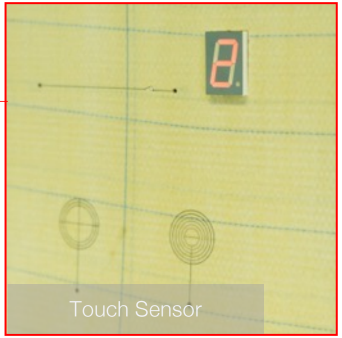


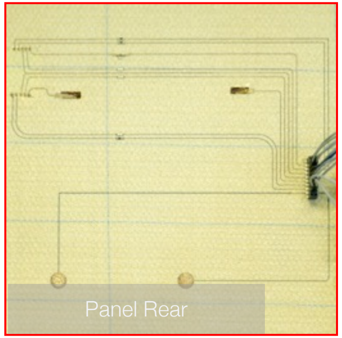
Thermal Anlaysis

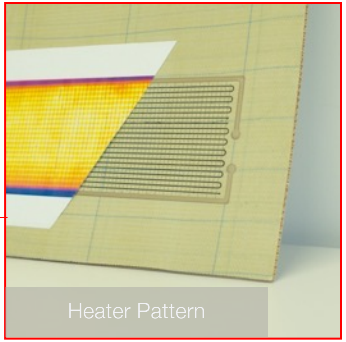
DLR: FeVedis Project
Fraunhofer PYCO, FAPS & Neotech

Smart Cabin Panel









DLR FeVedis Project

Partners:
Fraunhofer PYCO
FAPS
Neotech AMT

Printed Circuits & Sensors for Healthcare

After suffering a stroke patients are often accompanied by unilateral motor dysfunction resulting in weak finger strength, grip, and poor circulation.

The rehabilitation ball has printed circuits and embedded electronic components on curved, flexible substrates.

It is held in the palm of the hand for close-and-open exercises and effectively increases finger strength and stroke recovery.

The device provides real-time feedback the patient's grip strength and monitors the training process for patients.

Device developed and manufactured by EverYoung BioDimension Corporation

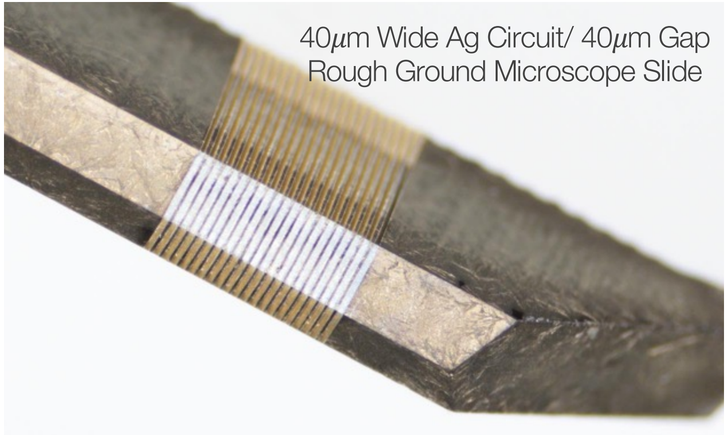
Touch Display Edge Wrap - PoC

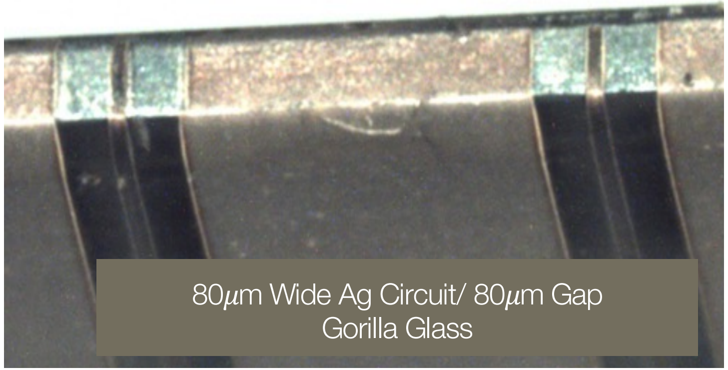
Traditionally edge wrap was done by flex PCB.

To save space printing techniques are being investigated:
a) Screen print – multiple steps, re-alignment but has yield issues
b) Direct printing via Aerosol – can print in 3D but circuit thinning at glass edges and is slow (<20mm/s) /expensive

Process Flow:
1. Fast printing of particle free Ag (front & rear at 45^{o} angle to coat edge)
2. Dry/Cure
3. Laser Abate

Fast & Low cost Manufacture -potential to produce 160.000 interconnects per hour with single print/laser station





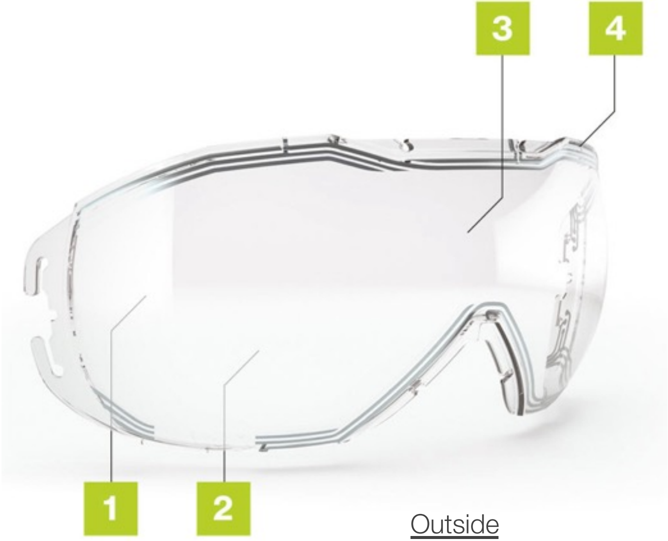
Wearables – Anti-fog & scratch-resistant safety glasses

Scratch-resistant and fog-/ice-free protective goggles with "built-in lens heating”

Unveiled at A+A 2021 - International Trade Fair for Safety, Security and Health at Work

Courtesy: UVEX ARBEITSSCHUTZ GMBH

https://www.uvex-safety.com/de/beschlagfreie-kratzfeste-und-eisfreie-schutzbrille-uvex-activision/



Inside
1. Anti-fog coating
2. Transparent, thermally conductive coating defrosts down to -20 ° C

Outside
3. scratch & chemical resistant coating

4. 3D conductor tracks

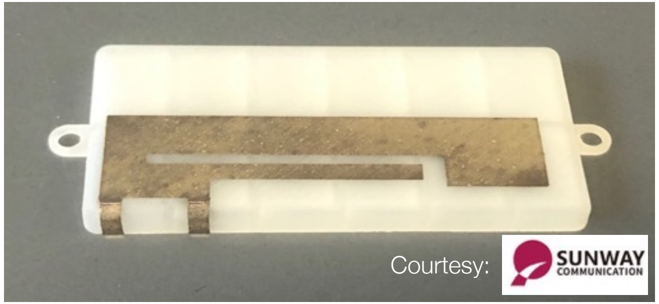
3. Markets & Applications

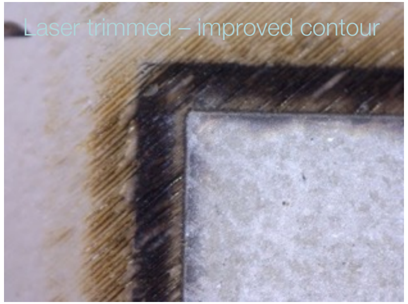
Route 2 - Fully Additive 3D Printed Electronics

Printing Electronics on 3D Printed Surfaces

All 3D Printed substrats show some surface texture that affects the printed electronics. Surface quaity depends on process: SLA and IJ show smoothest, SLS can be rough/open, FFF has texture from the extruded seam

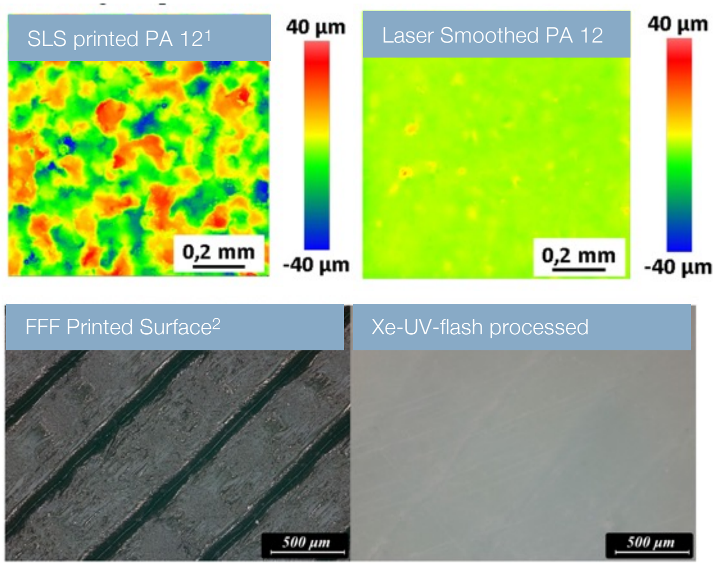
Example - Antenna Prototype
Substrate: Multijet printed thermoset photopolymer.
Exhibits fine resolution but still exhibits surface topography.
Inaccurate contour impacts on frequency matching and efficiency
Laser trim creates perfect contour

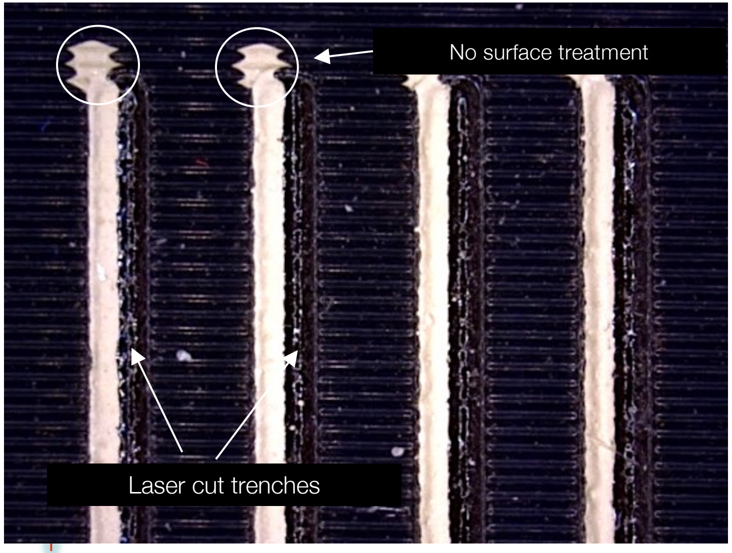




Printing Electronics on 3D Printed Surfaces

3D Printed substrates can show surface texture that affects the printed electronics.
SLA and IJ printed mechanical structures show smoothest and closed surfaces.
SLS[1], FFF[2], can benfit from pre-processing with lasers (smooting, ablation) or Xenon flash lamps.



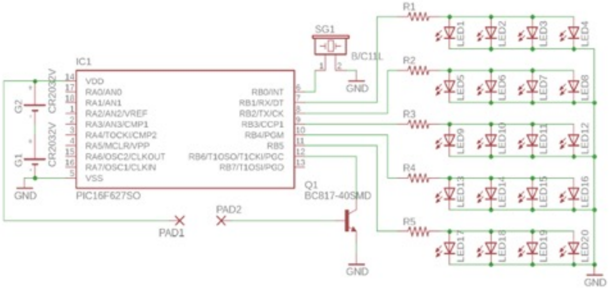


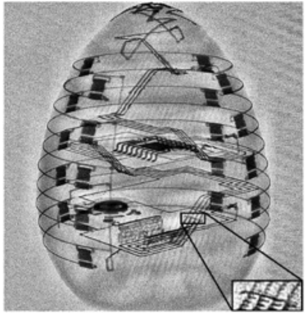
[1]Laser polishing as a new post process for 3D-printed polymer parts - Braun, Wilenborg, Schlifbaum - 11th CIRP Conference on Photonic Technologies - LANE 2020
[2] Pulse-Width Modulated Light Technology for Enhancing Surface Properties and Enabling Printed Electronics on FFF-Printed Structures - Graef, Neermann, Stuber, Scheetz, Franke – MID Congress 2018
[3] Laser-based generation of conductive circuits on additive manufactured thermoplastic substrates - Niese, Amend, Roth, Schmidt - 9th International Conference on Photonic Technologies - LANE 2016

3D Printed Egg Timer

FAPS – University Erlangen-Nuremberg

- 20 white LEDs mounted in five rings on the outer shell
- Embedded PIC16F627 microcontroller
- Powered by two 3 V button cells in series
- Touch switch realized by two comb-shaped pads and a transistor
- Piezo buzzer for acoustic signals
- Conductive path cumulative length of 2m





Luminaire Demonstrator

Cold-Warm LED Device

”Fully Additive Manufacture”

1.Mechanical Structure: FFF PC/ABS

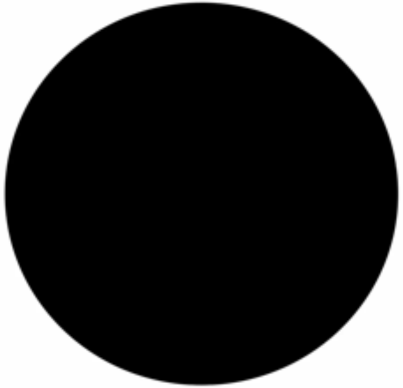
2. Piezo Jet of Ag circuits

3. P&P of SMDs:

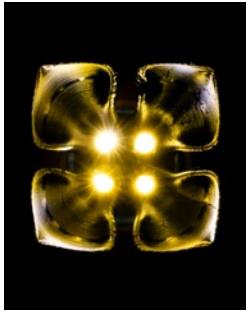
8 Cold & 4 Warm White LEDs

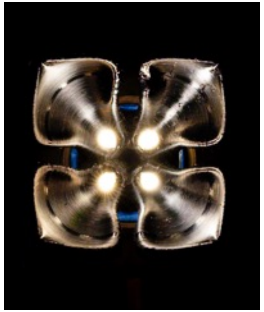
+ Controller, Capacitors, Resistors

4. Pellet Extrusion of transparent TPU



https://www.youtube.com/watch?v=obbZR7KrVpM&t=26s





4. Active Research & Future Perspective

AMPERE

Reliable and scalable hybrid manufacturing methods for smart systems

1. Further Develop “Fully Additive” 3D Printed Electronics – both flexible and scalable from small series mass customisation to higher production volumes.
2. Integrated mechanical, electrical and optical functionalities.
3. Develop scalable and <u>reliable</u> industrial production systems in combination with the essential technology and smart processes.
4. Demonstrate the hybrid manufacturing approach in three innovative product cases covering different applications and sectors (LED luminaires & signal and power electronics & medical devices).

Penta

AMPERE Project Partners

Processes, Materials & Equipment	Industrialisation	Products	
TNO, TU/e HTSC	reden, VSL	Signify	Luminaires
		PHILIPS	Medical Devices
Fraunhofer, XENON	Neotech AMT	Würth Elektronik	Power & Signal Electronics

Project Timeframe:1.4.21-31.3.24

AMPERE State of the Art – „Fully Additive“ 3D PE

Key technology		SotA
1	Additive Manufacturing/3D printing materials & processes	Demonstrated “Fully Additive” Process –Low power (mA range) printed electronics in AM polymer substrates, small lot size
2	AM Structural Materials	Monolithic thermo-plastics and UV Cured Acrylic Substrates
3	AM Optical Materials	Simple devices (waveguides) can be 3D Printed
4	Structural AM Scalability	Multiple printers - some limited machine throughput scaling under development
5	3D electronics integration/assembly	R&D processes (20um at <20mm/s) for fine line 3D circuit printing. SMD pick and place & interconnection possible
6	Software processes	CAD-CAM for manufacturing tool-path generation with all process steps
7	In-line metrology and control platform	Basic Metrology in process (mainly optical inspection)
8	Design Tools	Software to predict residual stresses demonstrated

AMPERE Beyond SotA

AMPERE Objectives (beyond SotA)		Benefit
AM Processes	Scalable process suitable for industrial use to lot sizes of 10.000	Lowest cost scalable product manufacture
		Unique new product offering for machine tool manufacturers
Process Control	Closed loop process control - combination of (in-line) metrology with AI/machine intelligence/learning	New SW & Consultancy Services
		Robust/reliable manufacture
		Added functionality of machine tools
AM Generated Functionality	Extend capabilities to enable signal and power electronics	New application range addressed
	Addition of optical structures, such as wave guides, light shaping or lens structures	Unique feature combinations in end products, extend market addressability
	Scalable fine line circuits	Miniaturisation of devices on a scalable production level

AMPERE Outcomes & Benefits

Outcomes

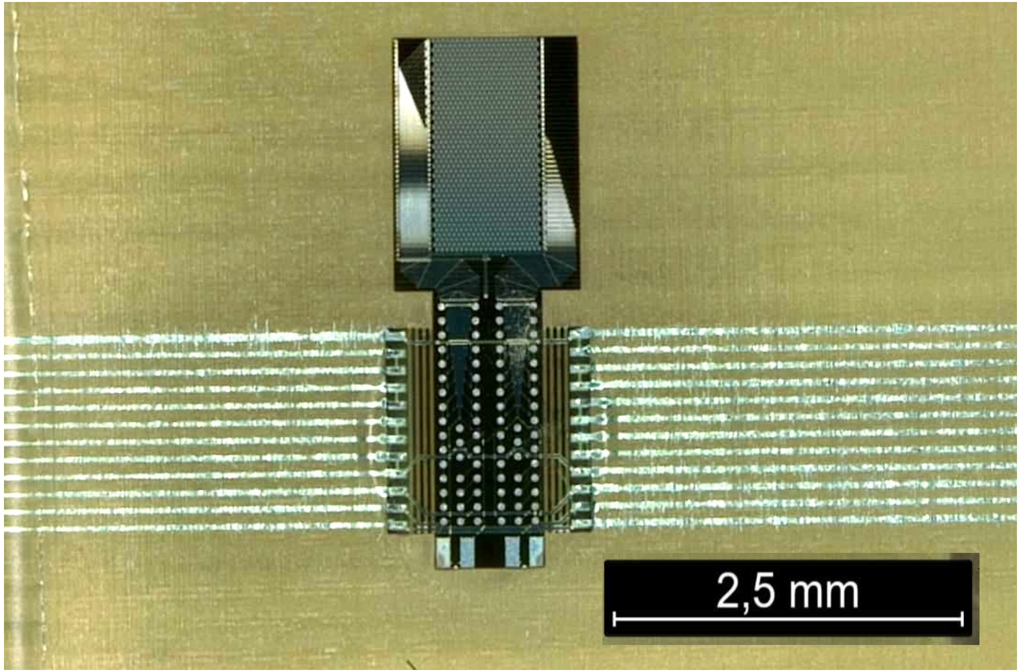
1. Hybrid multi-material AM production methodologies.
2. Demonstrated integrated production environment architecture.
3. prototypes of mechatronic products in three application areas: medical, lighting and power electronics.

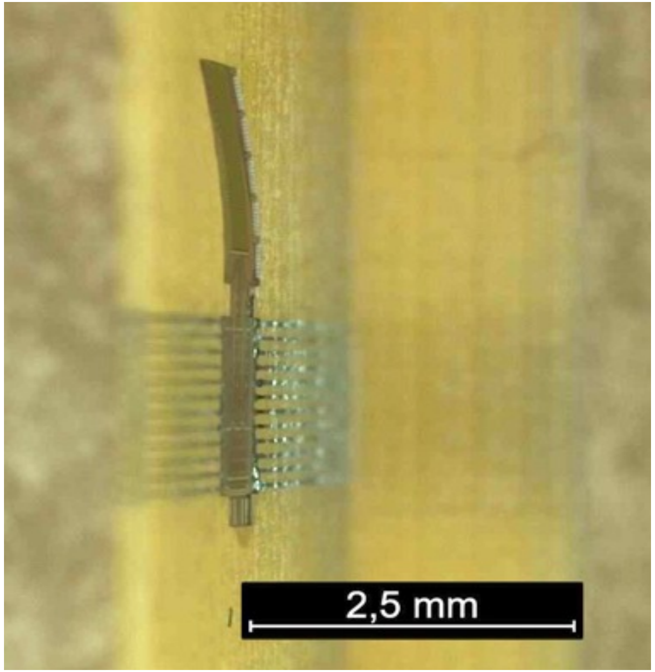
Benefits

1. Faster response to changes in the market - localized production and reduced component and tooling lead times.
2. Increased product diversity - flexible manufacturing technologies
3. Cost effective scalable manufacturing of small series and high volumes
4. New product designs - improved functionality, new form factors.

AMPERE First Technical Demonstrators

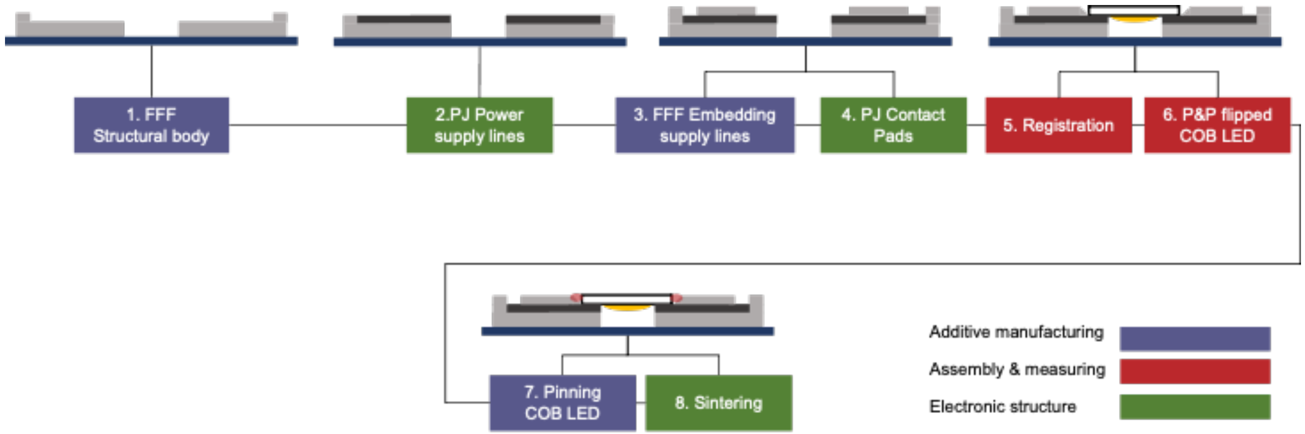
Philips Medical – Interconnected (20μm line & Space) ASIC/CMUT on SLA printed body

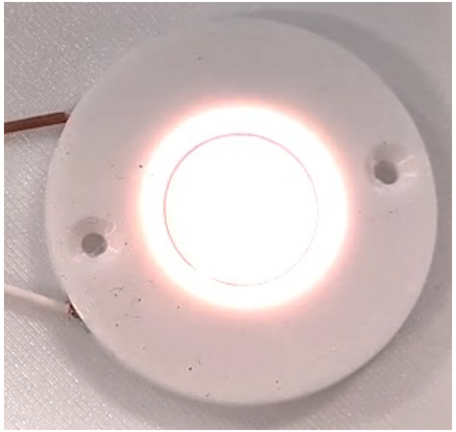




Signify – 3D Printed CoB LED Housing

Process Flow





KAM EI Project – Vision Based Automated QA

Development of a camera-based monitoring system for “Fully Additive” 3D Printed Electronics

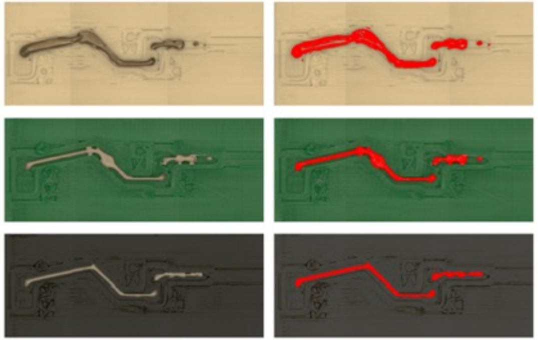
Record and classify the manufacturing process and automatically correct processing errors dependent on type:

1. Vision system will records the printed electrical structures in 3D space.

2. Images compiled, compensating for distortion and depth of field elements.

3. Artificial Intelligence (AI) to check for potential defects such as line breaks, short circuits and geometrical errors in width and thickness.

4. Defect is identified, one of three options that can be executed: automated correction, correction with operator input or part rejection (abort print).



Verification of the ink segmentation algorithm with different filament colours.
(University of Hamburg)

Project funded by:

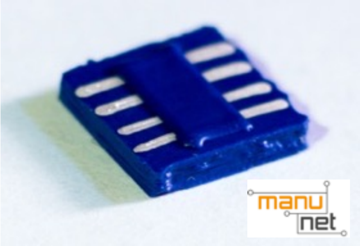
Bundesministerium für Wirtschaft und Energie

Timeframe:1.10.20-30-9.22

„Fully Additive“ 3D PE with Ceramic Substrates

1. EU Manunet Project AMPECS developed base process for Additive Manufacturing process for 3D Printing Electronics with Ceramic Substrates.

Cermaics based on LTCC analogue with embedded nano-particle Ag circuits.



2. Additive4Industry project PE3D Printed Electronics on 3D Substrates

ContiTemic microelectronic GmbH, FAU – Institute FAPS, GSB-Wahl GmbH, TNO (NL)

Development of Additive Manufacturing processes for LTCC ceramic substrates with integrated circuit tracks for high temperature automotive applications including HF/antenna and sensor units.

Additive 4Industrie

Bundesministerium für Bildung und Forschung

Grant number:
03INT709BD

MRO PrinE - Automated Repair of Printed Conductor Tracks

Approaches for Maintenance Repair and Overhaul

of Printed Electronics in Aircraft Cabin Interior components

for establishing printed electronics in aircraft applications

Process flow:

- Identify damaged area
- Remove printed conductors by laser ablation
- Surface reconstruction and preparation
- Re-printing and curing of conductor patterns

Step-by-step ablation of printed Ag

Funded by:

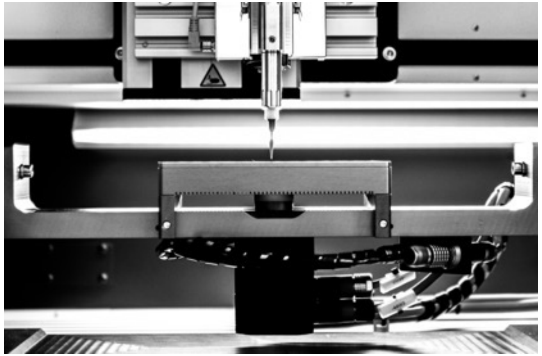
Federal Ministry
of Economics
and Technology

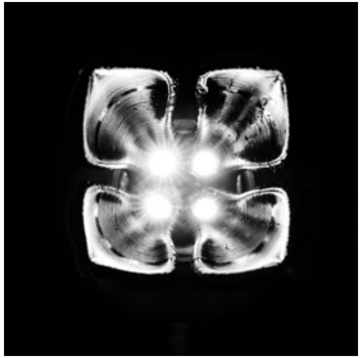
Grant: 20Q1728A

What does the future hold for 3D Printed Electronics ?

<u>3-5 Year Timeline</u>
First Complete Automated Processing Lines – Agile, on-demand digital manufacture
Smart Systems with AI/Machine Learning
Wider functionality: eg. power electronics (many A), optics, miniaturisation, large parts…
Wider adoption across many end use cases/industries

<u>10 Year Timeline</u>
Completely new product architectures
Sustainable 3D Printed Electronics - resource efficient, reduced materials mix
Automated Recycling, Repair and Reuse





Summary

1. What is 3D Printed Electronics, reasons for use and benefits.

2. 3D Printed Electronics Manufacturers, Systems & Strategies

3. Markets & Applications

Route 1 - MID Application Examples (Mechatronic Integrated Devices)

Route 2 – “Fully Additive” 3D Printed Electronics

4. Active Research & Future Perspective

Neotech AMT

Advanced Manufacturing Technologies for 3D Printed Electronics

Thank you for your attention!

Contact:

Dr. Martin Hedges

Neotech AMT GmbH

Fürtherstrasse 244a Hof C, 90429 - Nuremberg - Germany

Tel: +49 911 274 5501

mhedges@neotech-amt.com